Carrying capacity of Indian agriculture: Issues related to rainfed agriculture

Article in Current science · March 2012

Bandi Venkateswarlu
Vasant Rao Naik Maratwada Krishi Vidya Peeth , Parbhani , India

J.V.N.S Prasad
Central Research Institute for Dryland Agriculture, India

Carrying capacity of Indian agriculture: issues related to rainfed agriculture

B. Venkateswarlu* and J. V. N. S. Prasad

Central Research Institute for Dryland Agriculture, Hyderabad 500 059, India

Carrying capacity (CC) in the context of Indian agriculture, denotes the number of people and livestock an area can support on a sustainable basis. CC is dynamic in nature, varying from time to time based on utilization of resources, technology application and management. In India, rainfed agriculture occupies nearly 58% of the cultivated area, contributes 40% of country's food production, and supports 40% of the human and 60% of the livestock population. The food grains production has increased several fold in the last four decades. During the last decade (TE 1998–99 to TE 2008–09) the production in coarse cereals, oilseeds and pulses increased by 20%, 16% and 3% respectively, primarily due to the yield gains. There is a need to further increase food production substantially for meeting the requirements of the ever-increasing population. This will put tremendous strain on natural resources which are already under stress due to unsustainable utilization. Continuous decline in groundwater levels, growing deficiency of major and micronutrients, declining factor productivity and looming threat of climate change are some of the issues which will have a bearing on food production in the near future. However, the large realizable yield gaps in many rainfed crops, opportunities to increase yields through rainwater harvesting and recycling, soil fertility improvement, crop diversification and effective dissemination of technologies give a hope that future requirements of food can be met, but it requires substantial resources. This article discusses issues constraining rainfed crop production and possible ways to enhance productivity in a sustainable manner.

Keywords: Carrying capacity, land degradation, productivity, rainfed agriculture, sustainability.

Introduction

ECOLOGISTS define the carrying capacity (CC) of the ecosystem as the population of humans and animals that can be sustained, based on the primary productivity of plants, with the available resources and services without damaging the resource base – soil, water and environment[1]. CC is not a static number as land productivity can be enhanced with inputs of water, energy and plant nutrients. Global food productivity has increased several fold with the inputs of chemical fertilizers, water and inputs of energy derived from fossil fuels. However, considering the CC of Indian agriculture, we are mainly addressing the question of sustainable food production, but the issue of gainful employment and access to food would remain, which is the outside scope of this review. Since crop and livestock products are produced and consumed all over the country with free inter-state movement, CC in India can be studied and analysed only in the national context. Moreover, CC is dynamic in nature varying from time to time based on the status of utilization of resources, technology application and management. This article analyses the potential of rainfed agriculture to support the food, fodder, fuel and fibre needs of the population depending on it.

*For correspondence. (e-mail: vbandi_1953@yahoo.com)

Importance and contribution of rainfed agriculture

Rainfed agriculture with nearly 58% of the cultivated area contributes 40% of the country's food production. Even after full irrigation potential of the country is realized, half of the cultivated area will continue to be under rainfed farming[2]. Much of the acreage under coarse cereals (85%), pulses (83%) and oilseeds (70%), substantial area under rice (42%) and nearly 65% of cotton area is rainfed[3] (Table 1). Hence, it is necessary to increase the

Table 1. Area sown under various rainfed crops and percentage of rainfed area during 2008–09

Crop	Area sown (M ha)	Rainfed area (%)
Rice	45.5	42
Coarse cereals	27.5	85
Jowar	7.5	91
Bajra	8.7	91
Maize	8.2	75
Pulses	22.1	83
Redgram	3.4	96
Bengal gram	7.9	67
Oilseeds	27.6	70
Groundnut	6.2	79
Rapeseed and mustard	6.3	27
Soybean	9.5	99
Sunflower	1.8	69
Cotton	9.4	65

Table 2. Comparison of studies for demand projection for food grains in India

	Demand and supply projections (Mt)								
	Chand[5]			Singh[7]*			Amarasinghe *et al.*[6]		
Food grains	2004–05	2011–12	2020–21	2000	2030	2050	2000	2025	2050
Cereals	192.8	219.3	262	159	225	243			
Pulses	14.2	16.1	19.1						
Food grains demand	207.0	235.4	281.1				200	291	377
Estimated production				192	262	295	206	292	385
Surplus/deficit				+33	+37	+52	+2.8%	+0.2%	+2.0%

*Only for cereals.

productivity of major rainfed crops to meet the ever-increasing demand of food and fibre. Moreover, rainfed regions are home to about 40% of the human and 60% of the livestock population, and the performance of rainfed agriculture is critical to achieve and sustain higher growth in agriculture. Investments in irrigated areas continue to increase, their marginal returns come down gradually, whereas in the rainfed areas, the marginal returns from additional public investments in technology and infrastructure are larger[4]. Thus, rainfed agriculture assumes importance from the consideration of growth, equity and sustainability.

Expected food grains requirements by 2050 and the growth rates needed to meet the demand

Long-term trends in household-level consumption patterns show that per capita direct consumption of food grains has been declining and of livestock products, fruits and vegetables has been increasing for a fairly long time[5]. Despite this shift, food grains are of paramount importance for household food and nutritional security because cereals and pulses are staple foods and the cheapest sources of energy and protein for low-income groups, and the requirement as livestock feed is growing rapidly as the demand for animal products is increasing rapidly. Any slackness towards their production translates into persistent price rise with adverse impact on the nutritional levels of common people.

Amarasinghe *et al.*[6] estimated that the total calories requirement (kcal/person/day) has increased from 2495 in the year 2000 to 2775 in 2025 and 3000 in 2050. The consumption pattern of food grains, which contribute to major nutritional intake, is decreasing; it was 64% during the base year 2000, and may reduce to 57% and 48% during the projected years of 2025 and 2050 respectively. Contribution from non-grain crops and from other animal products is increasing. The contribution from non-grain crops was 28% during 2000, and is projected to be 33% and 36% during 2025 and 2050 respectively. Contribution from other animal products was 8% during 2000, which is projected to increase to 12% and 16% during 2025 and 2050 respectively. Taking these aspects into consideration, the total food grain demand is estimated to be 291 Mt by 2025 and 377 Mt by 2050, whereas the total production is estimated to be 292 Mt by 2025 and 385 Mt by 2050, which is more than 2.0% of the demand. However, production deficits are projected for other cereals, oilseeds and pulses. The projected deficit is 33% and 3% in 2025 and 43% and 7% in 2050 for other cereals and pulses respectively.

Another study[7] found the food consumption levels in India will increase from the current level of 2400 kcal/per capita/day to about 3000 kcal/per capita/day in 2050 and projected that the demand for cereals will rise to 243 Mt in 2050, an increase of 0.9% from 1999 to 2001. Over the same period, cropping intensity in India is also projected to increase only slightly, from 101% to 104% in rainfed areas, and from 127% to 129% in irrigated areas. The rainfed crop yield is expected to increase to 1.6 t/ha in 2015, 1.8 t/ha in 2030 and 2.0 t/ha in 2050. The irrigated cereal yields are projected to increase from 3.5 to 4.6 t/ha during the same period. The cereal production in India is thus projected to increase by 0.9% per year between 1999–2001 and 2050, and is expected to exceed the demand by 2050 even if the projected growth is about 0.9% per year (Table 2).

Recent production and productivity trends

During the last decade (TE 1998–99 to TE 2008–09), the area sown to coarse cereals fell by 8% (from 31 to 28 M ha), whereas production increased by 20% and productivity from 1042 to 1357 kg/ha because of the yield gains[3]. Within the coarse cereals, the area and yield increases were more conspicuous in the case of maize, but less area was sown to sorghum and pearl millet during TE 2008–09 than during TE 1998–99. In the case of pearl millet, the area declined from 9.65 to 9.28 M ha, but the yield increased from 776 to 981 kg/ha resulting in an increase in production by 21% (Table 3). The compound growth rates of coarse cereals for the period 1998–99 to 2008–09 increased at a rate of 2.7% though the area declined at a rate of 0.5% per annum. Among the coarse cereals, yield growth was fastest in case of pearl millet (4.0%) and slowest in case of sorghum (1.8%).

Table 3. Compound annual growth rate in area, production and yield of major crops in India, 1998–99 to 2008–09

Crop/crop group	Growth rate (%)		
	Area	Production	Yield
Sorghum	–2.8	–1.2	1.8
Pearl millet	0.1	4.1	4.0
Maize	3.0	5.6	2.5
Coarse cereals	–0.5	2.7	3.3
Chickpea	1.7	2.2	0.5
Pigeonpea	0.3	0.2	–0.2
Pulses	0.6	1.1	0.5
Coarse cereals + pulses	–0.03	2.2	2.3
Groundnut	–1.3	0.9	2.3
Castor	0.2	1.4	1.2
Sunflower	4.9	7.3	2.3
Soybean	4.4	5.6	1.2
Rapeseed and mustard	2.0	4.2	2.2
Oilseeds	1.6	3.6	2.0
Coarse cereals + pulses + oilseeds	0.5	2.7	2.2
Cotton	0.5	10.2	9.6
Rice	–0.1	1.3	1.4
Wheat	0.4	0.9	0.4

The area under pulses did not show much change between TE 1998–99 and TE 2008–09, as it stagnated at about 23 M ha and the production increased by about 0.5 M ha (3%). There was a marginal improvement in yield from about 612 to 632 kg/ha during this period. Chickpea and pigeonpea, the two important pulse crops accounted for about 60% of the total pulse production. The productivity of these two crops increased by about 3.1% and 2.5% respectively, between TE 1998–99 and TE 2008–09. The performance of pulses continued to be low. Both area and yield did not show any significant growth and as a result the production also increased at a mere 1.1% per annum.

The area, production and productivity of oilseeds increased by 2.6%, 16.1% and 13.1% respectively, during the last decade. Within oilseeds, the area sown to groundnut decreased from 7.4 M ha during TE 1998–99 to 6.0 M ha during TE 2008–09. Among other oilseeds, significant productivity growth was observed in rapeseed and mustard. Though the area under soybean increased conspicuously from about 5.9 to 8.9 M ha, this could not be translated into production gain as the yield levels increased by only 5.5% from 1055 to 1113 kg/ha during the last ten years. In case of oilseeds, yield growth was observed in rapeseed and mustard (2.2%) and groundnut (2.3%), and slower growth in soybean (1.2%). Growth rate in yield of coarse cereals + pulses (2.3%) and coarse cereals + pulses + oilseeds (2.2%) was higher than rice (1.4%) and much higher than wheat (0.5%). All the three crop groups, coarse cereals, pulses and oilseeds, whose production is largely rainfed, witnessed significant production and productivity growth during the last decade and compared favourably with that of rice and wheat[3]. The yield of pulses in India during 1998–99 to 2008–09 increased at a mere 0.5% per annum. About 81% of the production gains obtained in the case of oilseeds was accounted for by the increasing yields, indicating a strong role of technology-led production growth. An analysis of growth of major rainfed crops showed that there were significant production gains during the decade 1998–99 to 2008–09, and these gains were largely driven by yield growth. However, in many cases the production growth rate did not exceed the population growth rate, which has implications for food security.

The demand for animal feed and fodder resources is also increasing rapidly, whereas the area under pastures and the quality of pastures are decreasing. In 2003, India had 283.4 million bovines, 61.5 million sheep, 124.4 million goats, 13.5 million pigs and 489 million poultry. It is estimated that the livestock population has increased at a compound annual growth rate of 1.19% between 1951 and 1992. To feed the existing animal population, the required green and dry fodder is about 1025 Mt and 569 Mt respectively. Whereas the availability is about 390 Mt green fodder and 443 Mt dry fodder, leaving a large gap. The deficits are about 61% in case of green fodder and 22% in case of dry fodder. It is estimated that by 2025 the deficits will be to the tune of 65% in case of green fodder and 25% in case of dry fodder. Further, on account of diversified use of agriculture residues, the gap between the demand and supply of fodder is increasing (Figure 1).

Sustainability of the present growth rate

India has around 18% of the world population, 15% of the world livestock with only 2.3% of the total geographical area and 0.5% of pasture and grazing lands. The per capita availability of land has fallen drastically from 0.91 ha in 1951 to about 0.32 ha in 2001, and it is projected to decline further to 0.09 ha by 2050. The pressure on the land is increasing rapidly and land degradation is on the rise.

Deteriorating soil and water resources are posing serious problems to agricultural production. Of the total degraded land of 121 M ha, area affected by water and wind erosion constitutes 78%, which is predominantly rainfed. In India, 39% of the area has soil loss rates more than the permissible levels and 11% of the area falls in the very severe category where soil loss is more than 40 t/ha/yr, resulting in reduced productivity. Accelerated soil loss has contributed to substantial yield loss in many crops in India. In alfisols, yield losses were 138, 84 and 51 kg/ha for sorghum, pearl millet and clusterbean respectively, for every centimetre of loss of topsoil[8]. Deficiency of N is widespread with 89% of soils having low to medium N status. The status of phosphorus is low in 80% of the soils and that of potassium in 50% of the soils. Sulphur, Zn, Mn and Fe deficiencies are increasing

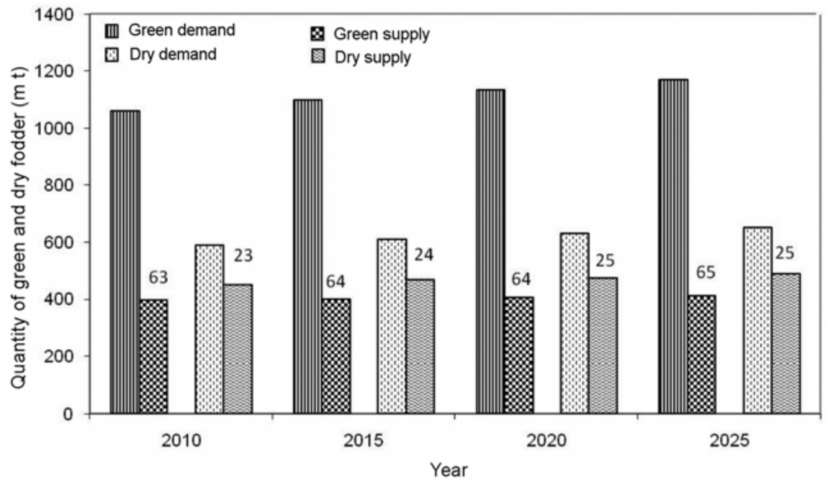

Figure 1. Supply and demand of green and dry fodder (Mt).

rapidly in several locations of the country. Zinc deficiency has been reported from Punjab, Haryana, Madhya Pradesh, Tamil Nadu, Andhra Pradesh and Uttar Pradesh, copper deficiency is acute in Uttar Pradesh and boron deficiency in Bihar and North Bengal. The quality of Indian soils is gradually eroding at the farm and ecosystem level. The major threats to soil quality emerge from loss of organic carbon, nutrient imbalance, compaction, salinization, waterlogging, decline in biodiversity, contamination with heavy metals, etc. The efficiency of fertilizer N seldom exceeds 40%, and that of phosphorus and micronutrients is only 20% and 2% respectively, even with the best management practices[9]. Maintaining natural resource base is a prerequisite for higher and sustainable agricultural growth.

There has been a rapid expansion in groundwater utilization since the eighties with the availability of subsidized power and pumpsets in rural areas, and the exploitation has reached critical levels in several districts in India. Uncontrolled groundwater extraction contributes to physical water scarcities, groundwater depletion-related environmental issues, loss of crops and investment, etc. Many river basins are likely to witness physical water scarcity by 2050. The degree of development of 10 river basins covering 75% of the total population will be over 60% by 2050. These water-scarce basins would have developed much of the potentially utilizable water resources by the second quarter of this century. Increased groundwater irrigation would have severe detrimental effects on many basins and groundwater extraction ratios of many basins are significantly high. Taking into consideration the recharge patterns in these basins, the groundwater use is not sustainable. Moreover, the water demand for non-agricultural sectors is projected to increase to 22% by 2025 and 32% by 2050, mainly due to the demand from domestic and industrial sectors, which will result in significant water transfers from irrigation. The irrigation sector which consumes as much as 83% of the available water resources, may have to reduce to 72% and 68% in 2025 and 2050 respectively. In contrast, the share of the industry sector[10] would increase from about 3% at present to 8% in 2025 and 7% in 2050. A similar trend is estimated in the drinking water and energy sectors. Reduction in the share of agriculture in the total water use will have serious implications for meeting the food production targets.

The impact of global warming on performance of the farm sector may become clear by 2035, when the expected rise in temperature will be 1.5°C. This will have considerable negative effect on food production and productivity. Recent studies indicate the possibility of loss of 4–5 Mt in wheat production with every 1°C temperature rise throughout the growing period. It has been estimated[11] that with a rise in temperature of 2.5–4.9°C, rice yields get reduced by 15–45% and wheat yield by 25–55%. The projected increase in droughts, cyclones, extreme precipitation events and heat waves will result in greater instability in food production.

Environmental trade-offs of accelerated growth

In order to achieve balanced nutrition and inclusive growth, considering the trend of diversification of the food basket, maintaining a steady growth in cereals, pulses and oilseeds and an accelerated growth of livestock, fishery and horticulture sub-sectors will be required in rainfed areas. Though it is a challenge, technological applications and use of quality seeds, fertilizers and water and its timely supply, would be the major determinants of growth in future.

Among the resources, fertilizer is one of the costly inputs, whose judicious use would trigger the process of accelerated growth in production. The current gap between nutrient removal and application is 10 Mt, which is likely to grow further. To meet the demand of food grain needs of the 1.4 billion projected population by 2025, it is necessary to use 30–35 Mt of NPK from fertilizers and

10 Mt from organic and biofertilizer sources[12]. Thus it is necessary to raise fertilizer production by 2025. Estimates based on the sufficiency approach show that the requirement for zinc will be 324, iron 130, copper 11, boron 3.9 and manganese 22 thousand tonnes by 2025. Site-specific nutrient management ensures targeted application of major and micronutrients at specified quantity for each holding, but is knowledge-intensive and requires substantial investments in terms of upgradation of soil testing infrastructure, manpower and extension services.

Use of fertilizers in drylands is limited. However, application of recommended quantum of fertilizers and integrated nutrient management practices have shown to increase the productivity of several dryland crops up to 15–32% (ref. 13). Soils under rainfed conditions have very low organic matter. Without regular application of organic manure and recycling of crop residues, we cannot hope to maintain and sustain productivity and ensure high responses to NPK fertilizers. Application of integrated nutrient management practices is extremely important and requires innovative approaches to produce organic resources on the farm itself by leveraging programmes like NREGS. Likewise, customized fertilizer formulations may be easier to push in drylands than individual components. In this endeavour, the performance of public sector soil-testing laboratories has not been satisfactory. There is a huge scope for public–private partnership in soil testing, promoting site-specific nutrient management and use of customized fertilizers.

In India, the additional net irrigated area (approximately 84%) in the past two decades has come from groundwater development. At present, net area irrigated by private tube wells is double that of canals. Groundwater provides 70% of the irrigation and 80% of the drinking water. Indiscriminate over-exploitation of groundwater is shrinking the resource base, as wells fail because of the fall in water tables and farmers are left in economic distress. The present scenario in India with respect to water management is turbulent. It is estimated that by 2050, about 22% of the geographical area and 17% of the population would be under absolute water scarcity, with water availability of less than 1000 m^3 per capita per year. There is a growing consensus that the current pattern of water resources development and management is not sustainable.

The pressure on the land for meeting the food demands will lead to greater intensification, resulting in further land degradation. The rainfed arable lands which are more affected by water and wind erosion are prone to this degradation. There should be renewed emphasis on conservation aspects such as reduced tillage systems, residue retention and management in rainfed systems. Retaining crop residues is reported to reduce the run-off and improve the soil carbon storage. The Government of India has allocated substantial resources for arresting further degradation and for treating the degraded land through various land-based development programmes. The resources allocated for such programmes (e.g. IWMP, DPAP, DDP, etc.) since independence is about Rs 19,251 crores, which could treat about 51 M ha. It requires substantial resources for treating all the degraded lands in a reasonable time-frame.

Rainfed regions are characterized by high climatic variability in time and space, which warrants greater emphasis on water harvesting and recycling and requires substantial resources at the farm level. Water harvesting in farm ponds, and recycling and the required infrastructure for life-saving irrigation need greater deployment of financial resources and tactful leveraging of ongoing schemes like NREGS, NHM and micro-irrigation.

Productivity levels that can be achieved on a sustainable basis

There is a scope for large yield improvements under rainfed conditions. The potential yields that can be attained and the actual yields for some of the dryland crops are presented in Table 4. With advanced management and high input levels, yields can be improved two to five times the current levels. Specialized dryland management practices such as water harvesting and reduction of soil moisture loss can increase yields by an additional 5–15% on average[14] across the SAT regions and reduce the variability in yields from year to year, producing a more reliable yield. Besides, the potential productivity varies with the rainfall and the crop growing season of a region. In the case of maize, the potential productivity for the high-rainfall regions is 8020 kg/ha, whereas the current national average is about 2062 kg/ha, indicating an unbridged yield gap of 5952 kg/ha. There are many districts in India where the actual yields are lower than the national average and enormous potential for improvement exists. In the case of rainfed rice, which contributes 55% of the total area under rice, the average yield is about 1 t, and the extent of adoption of high-yielding varieties is to the extent of 32% and the achievable yield is to the tune of 2500 kg/ha (K. P. R. Vittal *et al.*, unpublished).

The CC of land depends on the climate, resources available and per capita consumption of food and other resources. A minimum economic holding size of 2 ha of

Table 4. Potential and attainable yields (kg/ha) of some of rainfed crops

Crop	Potential yields attainable	Actual yields (TE 2007–08)	Difference	Quotient
Sorghum	4560	902	3658	5.0
Maize	3870	2062	1808	1.9
Pearl millet	2870	906	1964	3.2
Groundnut	2590	1171	1419	2.2
Soybean	2850	1089	1761	2.6

unirrigated land and 1 ha of irrigated land has been suggested in India for sustaining a family size of 5 or 6 persons[9]. The CC can be enhanced with technological, financial and managerial inputs. With the available technology and inputs, the rate of growth of agricultural production can be increased substantially. However, the sustainability of these practices depends on the resource endowments of a region and deployment of the technology itself. Judicious use of inputs and the enabling policy environment will lead to meeting the food grains and the multifarious requirements of the growing population in the years to come.

Meeting the challenges for 2050

The strategy for yield improvements in drylands is to be based on four pillars, viz. resource conservation, optimum use of rainwater, bridging the yield gaps, and innovations in technology transfer and upscaling. There is considerable scope for increasing the food grain production by harnessing the existing untapped potential. Average yields of several major crops can be improved further as potential yields of these crops on the farmers' fields with the adoption of improved practices are quite high. The large yield gaps indicate that crop output can be substantially raised through effective dissemination and adoption of improved technologies, particularly in eastern India. The existing socio-economic, infrastructure and institutional constraints, which are responsible for these gaps, need to be addressed first.

In India, about 114 billion cubic metres (BCM) of run-off is generated from 28 M ha of rainfed area in central and eastern India, with high potential for run-off. About 25 M ha of rainfed area can be provided with one supplemental irrigation (10 cm), with an estimated harvestable surplus of 28 BCM during a normal year and about 20 M ha during a drought year. By introduction of supplemental irrigation, the crop production can be enhanced by a total of 28–36 Mt from an area of 20–25 M ha during drought and normal monsoon periods, which accounts for about 12% increase over the present production from these areas. With the adoption of improved technologies, production can be further increased (Figure 2). The benefits could be still higher if improved irrigation techniques like drip and sprinklers are used. In order to realize the above projected benefits, Rs 63 billion per annum for 20 years (a total of Rs 1260 billion) is needed to develop 50 million ponds in rainfed areas spread across the country[15].

In situ water harvesting using simple technologies (vegetative barriers, gravel and stone mulching, compartmental bunding, cover cropping, inter-plot rainwater harvesting, dug-out ponds, percolation tanks, ridges and furrows, etc.) enables greater water infiltration and prolongs the availability of moisture under rainfed conditions. Technologies such as compartmental bunding are found to improve the yields up to 40–50% in the northern dry zones of Karnataka, and supplemental irrigation to groundnut in Rayalaseema has increased the yield up to 25% (ref. 13). In the eastern and central Indian states, the utilization of groundwater is less than the national average and scope exists for its safe usage. Water users groups need to be created for ensuring efficient utilization of available resources (both surface and groundwater) and sharing of water resources within a watershed, including minor irrigation schemes on the lines of water user associations in canal command area. It is essential to meet the nutrient deficiencies and enhanced requirements through INM to meet the food production goals. Timeliness in the availability of fertilizers is one of the important issues, particularly for rainfed regions. The emphasis should be on improving the fertilizer use efficiency. To operationalize INM, the major constraint is the availability of organic manure. With decline in cattle population, FYM availability is a question mark and hence we must make efforts to produce nutrient-rich biomass in the farm itself, particularly in medium and high-rainfall regions without interfering with the main crop season. For this, schemes like NREGS can be utilized to meet the labour component.

There is scope for accelerating agriculture growth through diversification into high-value crops, horticulture and livestock-based enterprises. Technologies are available for different agro-climatic regions of the country to improve biomass productivity, livestock production and various alternate land-use systems, including horticulture. The existing unutilized and underutilized degraded lands

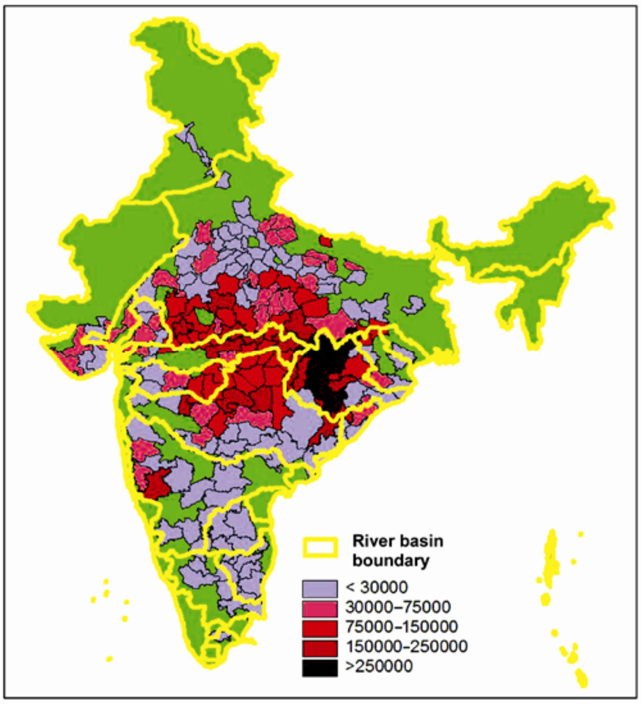

Figure 2. Spatial distribution of surplus run-off (ha-m) across districts and river basins.

and degraded pasture lands can be brought under silvo-pasture land-use which helps in not only arresting land degradation but also improves the biomass productivity. Timeliness of operations in rainfed agriculture is critical for achieving higher yields, and the use of farm machinery and equipment enables to cover larger areas in a short time. However, most often, farmers cannot afford to buy these equipment. A country-wide programme of promoting custom hiring services is one sure way of achieving higher yields in rainfed crops.

Intensification of land use in medium to high rainfall areas and arresting land degradation through integration of tree and fodder component provide leaf fodder in arid, semi-arid and hill regions of India during the lean period. Technologies for fodder production and agroforestry systems for various rainfed regions are available, which will increase the biomass productivity. Programmes like MGNREGA, watershed development and other land development programmes should be made use of for arresting land degradation and establishment of vegetation in degraded and community lands. Adaptation and mitigation strategies to address the impact of climate change on agriculture are needed urgently through new research for different agro-climatic settings. Use of alternative crops/ cultivars adapted to the likely changes, alteration in the planting date, management of plant spacing and input supply might help in reducing the adverse impact. Use of resource-conservation technologies and a shift from sole cropping to diversified farming system have great scope. Horticulture and agro-forestry need to be given more encouragement. Climate change could also offer some positive benefits in terms of opening up of new areas for cultivation of food crops due to changes in the temperature regime and more certain surface-water harvesting possibilities due to more intense rainfall pattern.

In dryland agriculture, legumes as a part of the crop rotation, as sole, inter and relay crops, are important both for improving productivity and sustainability. Location-specific technologies and strategies need to be developed for integrating legumes into the prevailing cropping systems. Enabling policies on crop insurance, subsidies and pricing related to water and energy uses need to be strengthened to reduce the variability of the production from rainfed systems. Also, it is necessary to develop a robust early warning system and weather-based advisories for taking up timely and effective field operations.

Conclusion

Sustainable agriculture is possible only for a steady population. As India is marching ahead to be the most populous nation by 2050, there should be more proactive approach for sensitization on population control and stabilization. Estimation of precise CC is not easy due to several variables associated with the production and consumption of resources in different societies. However, technological developments and various developmental programmes have substantial impact on productivity enhancement. In order to further enhance the productivity, we need to pay attention to soil health, prudent management of water resources, strategic application of improved production technologies and above all, innovations in technology transfer and upscaling by leveraging the ongoing development schemes.

1. Daily, G. C. and Ehrlich, P. R., Population, sustainability and earth's carrying capacity: A framework for estimating population sizes and lifestyles that could be sustained without undermining future generations. *Bioscience*, 1992, **42**, 761–771.
2. CRIDA – Perspective Plan Vision 2025. Central Research Institute for Dryland Agriculture, Hyderabad, 2007, p. 52.
3. Raju, B. M. K., Venkateswarlu, B. and Rao, C. A. R., Growth performance of major rainfed crops in India. *Indian J. Dryland Agric. Res. Dev*., 2010, **25**, 17–22.
4. Fan, S., Hazell, P. and Haque, T., Targeting public investments by agro-ecological zone to achieve growth and poverty alleviation goals in rural India. *Food Policy*, 2000, **25**, 411–428.
5. Chand, R., Demand for food grains during the 11 Plan and towards 2020. Policy Brief No. 28. National Centre for Agricultural Economics and Policy Research, New Delhi, 2009, pp. 1–4.
6. Amarasinghe, U. A., Shah, T. and Anand, B. K., India's water supply and demand from 2025–2050. Business-as-usual scenario and issues, 2007; www.iwmi.cgiar.org/.../NRLP%20Proceeding-2%20Paper%202.pdf
7. Singh, R. B., Towards a food secure India and South Asia. Making hunger a history, 2009; available on line http://www.apaari.org/wp-content/uploads/2009/08/towards-a-food-secure-india-making-hunger-history.pdf
8. Vittal, K. P. R., Vijayalakshmi, K. and Rao, U. M. B., The effect of cumulative erosion and rainfall on sorghum, pearl millet and castorbean yields under dry farming conditions in Andhra Pradesh. *Exp. Agric*., 1990, **26**, 429–439.
9. National Academy of Agricultural Sciences, Natural resources. In *State of Indian Agriculture* (eds Rai, M. *et al.*), NAAS, New Delhi, 2009, p. 248.
10. Ministry of Water Resources, Integrated water resources development: a plan for action. Report of the National Commission for Integrated Water Resource Development. Government of India, 1999, vol. 1, p. 515.
11. Parikh, K. S., Can India feed itself? In *Energy and Food Security* (eds Malik, S. K. and Vardarajan, S.), Indian National Science Academy, New Delhi, pp. 91–109.
12. Kanwar, J. S., Fertiliser policy issues 2000–2025. NAAS Policy Paper 2, New Delhi, 1997, p. 6.
13. Venkateswarlu, B., Mishra, P. K., Chary, G. R., Sankar, G. R. M. and Reddy, G. S., A compendium of improved technologies. AICRPDA, CRIDA, Hyderabad, 2009, p. 132.
14. Fischer, G., Velthuizen, H. V., Hizsnyik, E. and Wilberg, D., Potentially obtainable yields in the semi arid tropics. Global Theme on Agroecosystems Report No. 54, ICRISAT, Hyderabad, 2009, p. 68.
15. Sharma, B. R., Rao, K. V., Vittal, K. P. R., Ramakrishna, Y. S. and Amarasinghe, U., Estimating the potential of rainfed agriculture in India, prospects for water productivity improvements. *Agric. Water Manage*., 2010. **97**, 23–30.